Finite State Machines for Creating, Evaluating, and Refining Air-to-Air Combat Tactics

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# Evolution of Unmanned Military Aviation

Reconnaissance
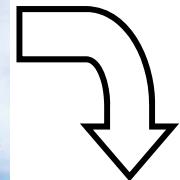
Air-to-Ground

Air-to-Air

APL
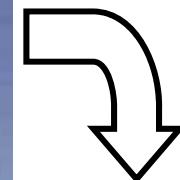
Why Don't We Have Air Superiority UAVs Yet?

- **Still lots of low-hanging fruit in ISR / ground attack**

- **No sense of urgency**
  - Our manned fighters and pilots are head and shoulders above the competition
  - This will change as soon as an Iranian UCAV shoots down an F-16

- **Control logic is more difficult**
  - ISR: Fly from A to B; snap a picture
  - Air-to-Ground: Fly from A to B; drop a bomb
  - Air-to-Air: Umm… Well…

APL

Who Will Teach the UAV Air-to-Air Tactics?

Create Building Blocks

Put the Pieces Together

APL

# Vision for Autonomous Air Combat Tactics Design

- **Professional tactician designs tactics visually**
  - No programming experience necessary
  - Inputs and outputs in terms pilots understand

- **Evaluate tactics before use**
  - In simulation
  - Using mathematical proofs

- **Monitor performance during/after engagement**
  - Understand thoroughly the strengths and weaknesses

- **Refine tactics in the field**
  - After short engagements
  - During long engagements?

APL

ExecSpec:
State-Machine Autonomy System

- **Developed for unmanned spacecraft**
  - APL internal and NASA funding

- **Visual, building-block design environment**

- **Automated verification**
  - Prove that specification requirements are met
  - Provide counter-examples if not met

- **Upload to spacecraft and execute**
 - Input file only; *not* a new executable

- **Real-time visual feedback**

Execute

Upload

Design   Test

Visualize

APL
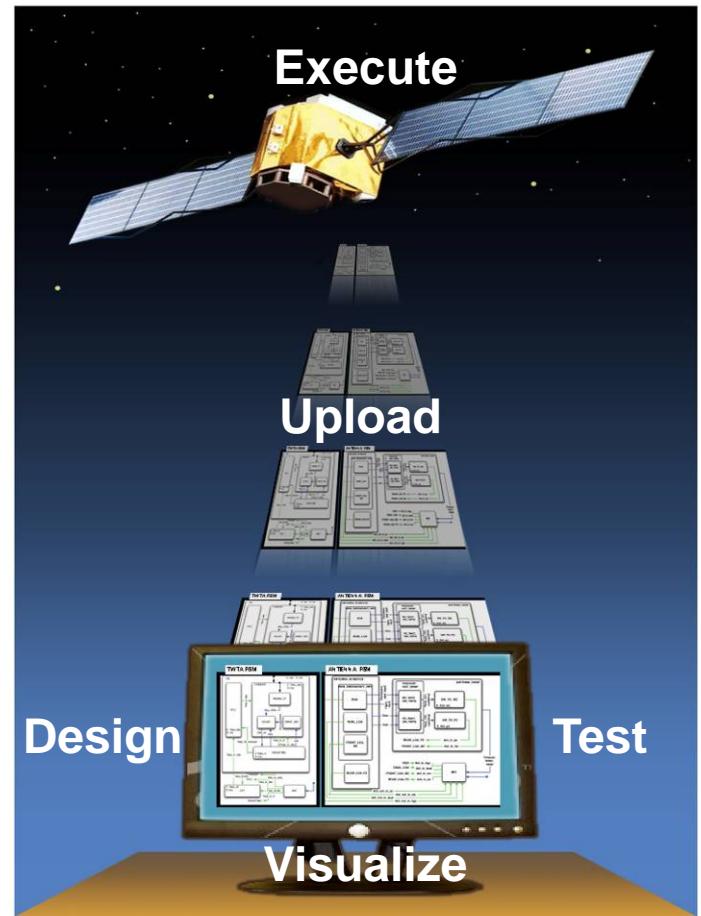
Representing Tactics as State Machines

Nose-to-Nose Turn   **Nose-to-Tail Turn**

Primitive Operations

+
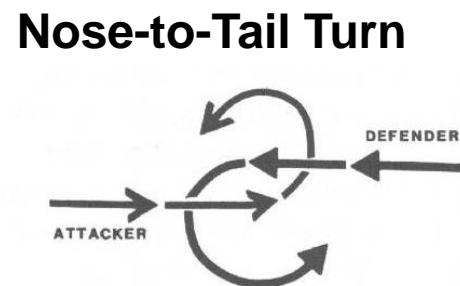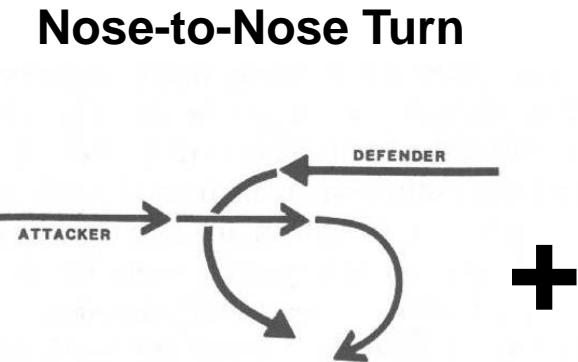
State machine times the reversals and determines when/whether to disengage

=

Flat Scissors

APL
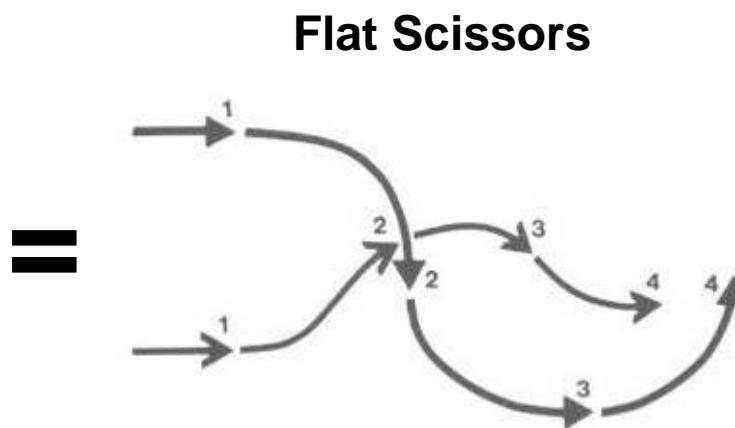
State Machine Example: Scissors
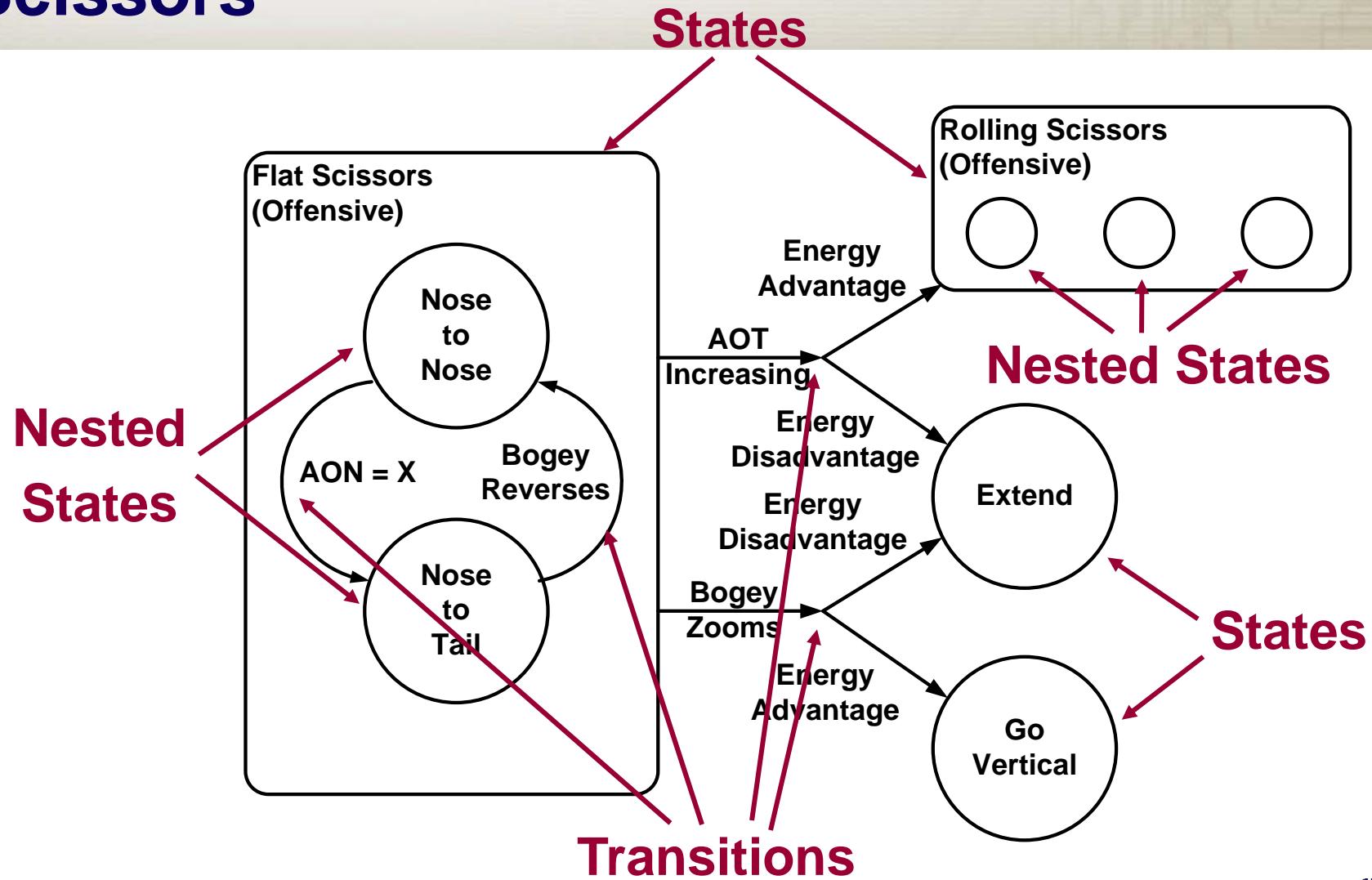
State Machine Example:
Missile Avoidance

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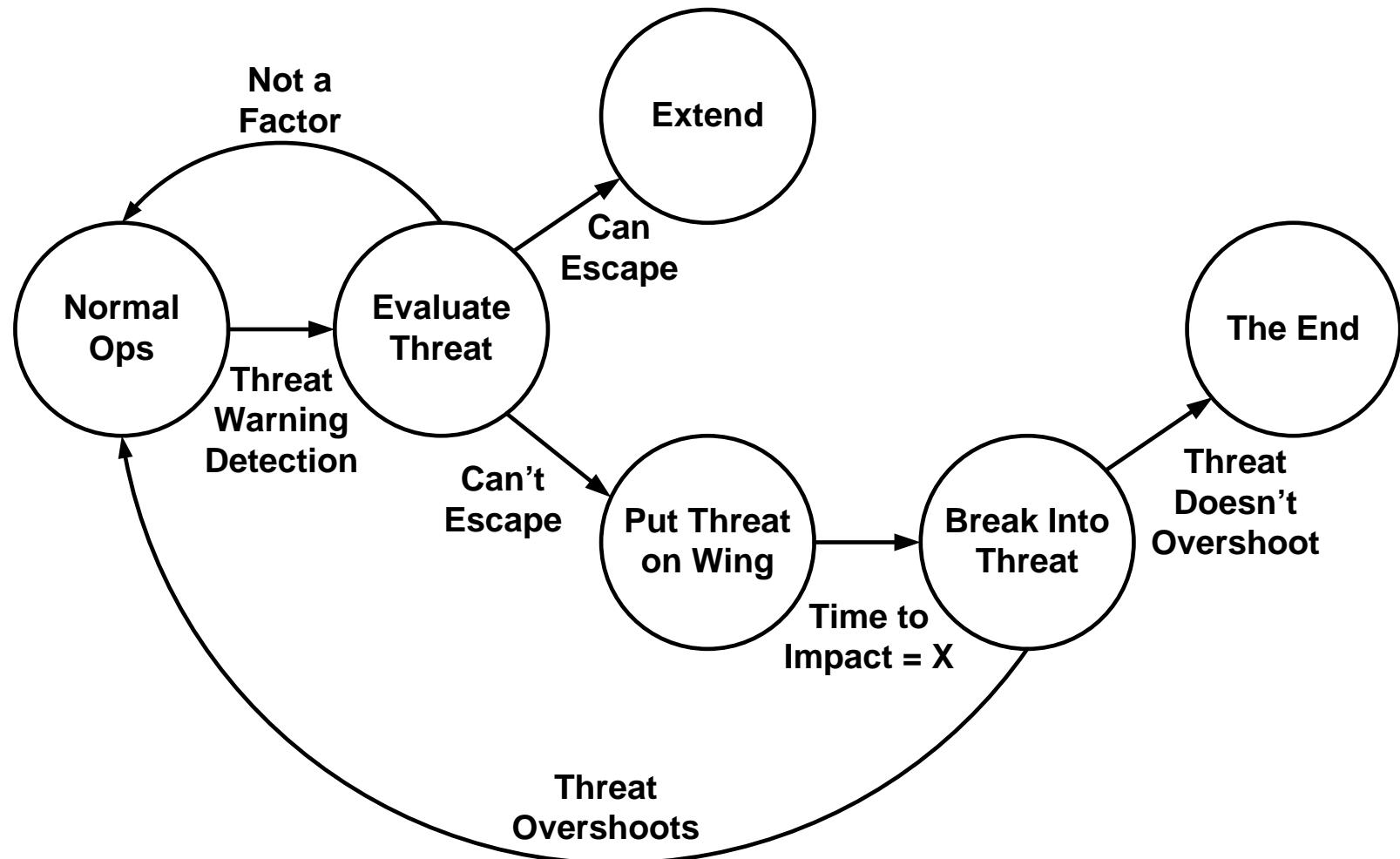
State Machine Autonomy Architecture

Finite State Machine Interpreter

inputs

outputs

- trackCrossingAngle
- flightPathSeparation
- relativeEnergy

- leadTurn()
- noseToNose()
- noseToTail()
- extend()

events	Tactical Layer	commands

Sensor Processing	Autopilot	
360° Sensors	GPS	INS

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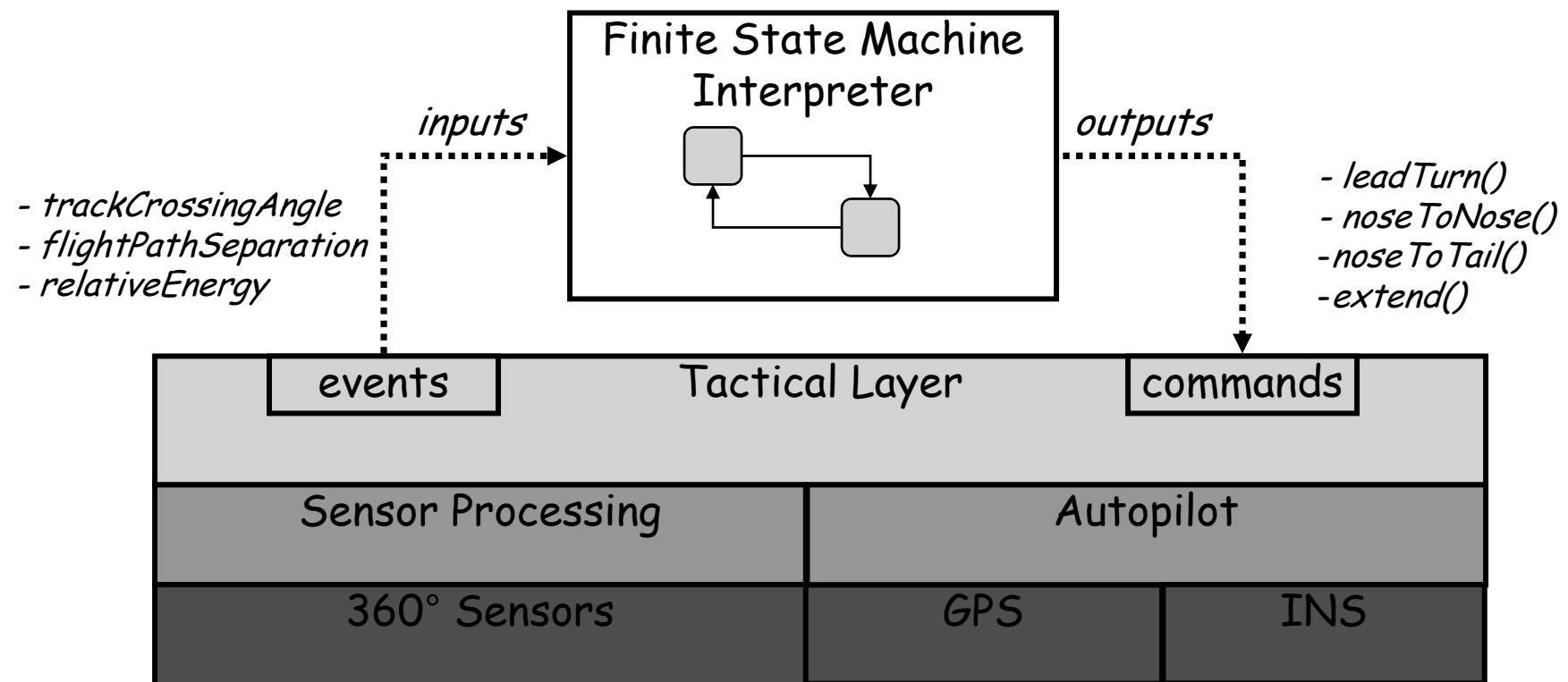
Design and Visualization Environment

Timeline

Design Palette

Inputs

State Machine

Outputs

Current State
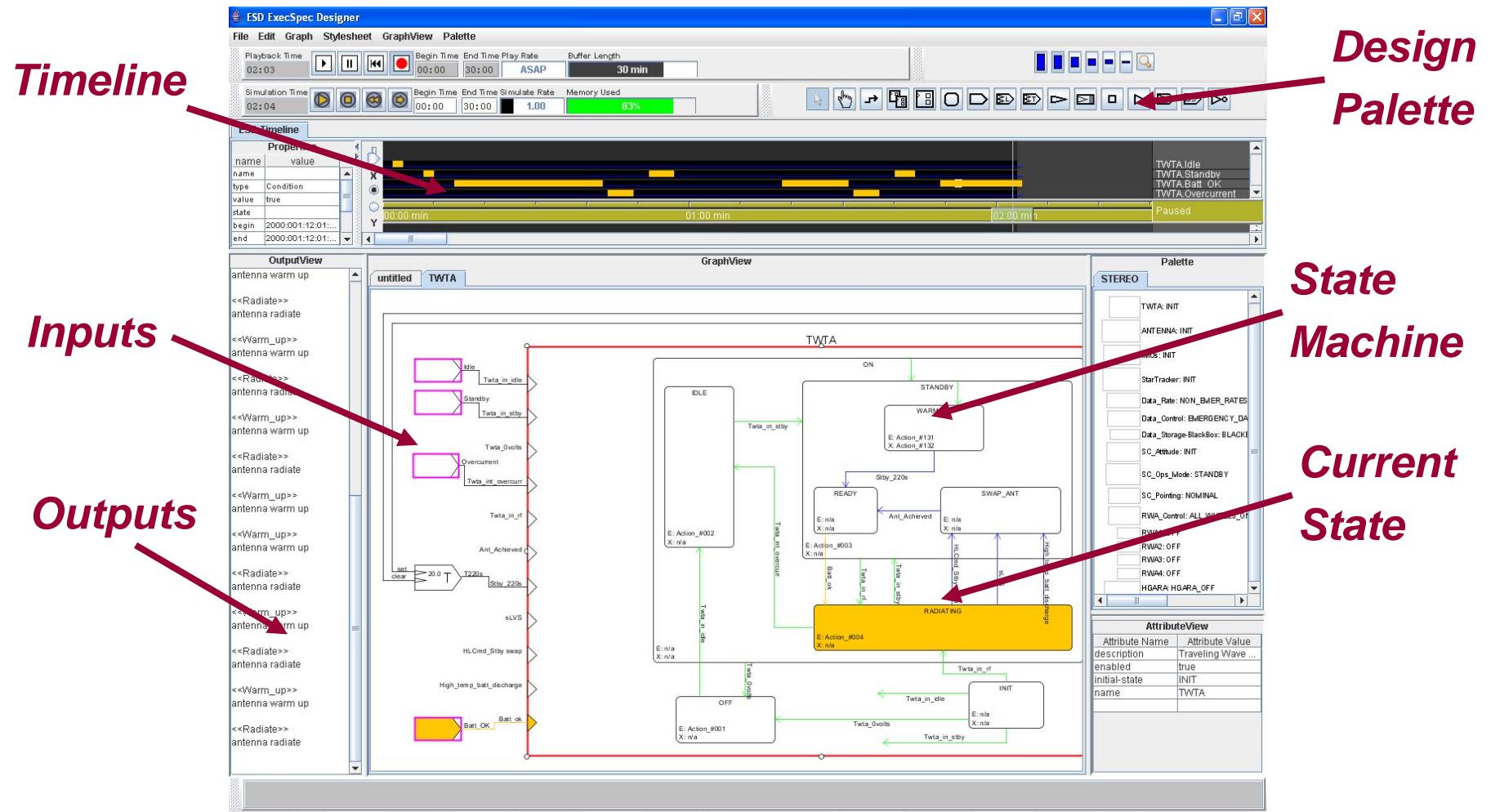
State Machine Verification: Model Checking

- **Mathematical methods can prove / disprove statements about state machines**
  - **X can never happen**
  - **Y will always be true**

- **Provides counterexample if statement is disproven**

- ***Both* the control logic *and* the plant dynamics must be modeled as state machines**

- **We use open-source NuSMV model checker**
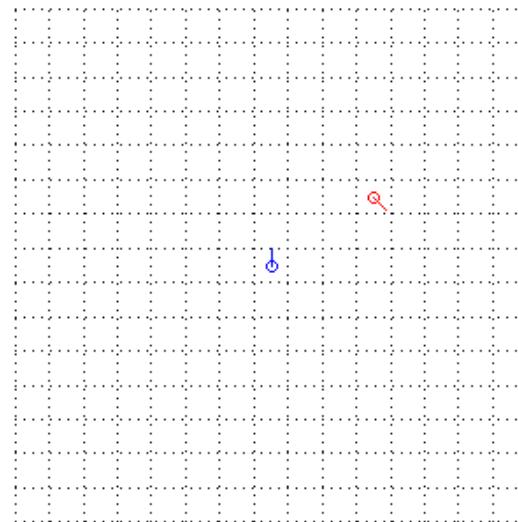
Relative Geometry

Maneuvers

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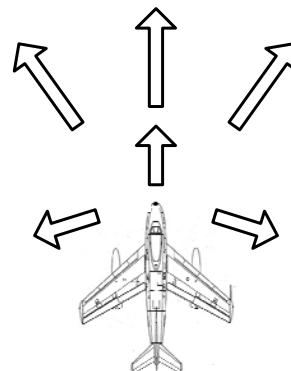
Verifying Air-to-Air Tactics

- **Setup**
  - Identical aircraft
 - Rear-quarter weapons only
  - Head-to-head start

- **Tactics**
  - Copycat
  - Mirror
  - Copycat with Delay
  - Mirror with Delay

- **Results**
  - Adversary *cannot* win against Copycat or Mirror without Delay
  - Adversary *can* win against Copycat or Mirror with Delay
  - Key factor:
    turn rate relative to time delay

Counter-example: Copycat with Delay
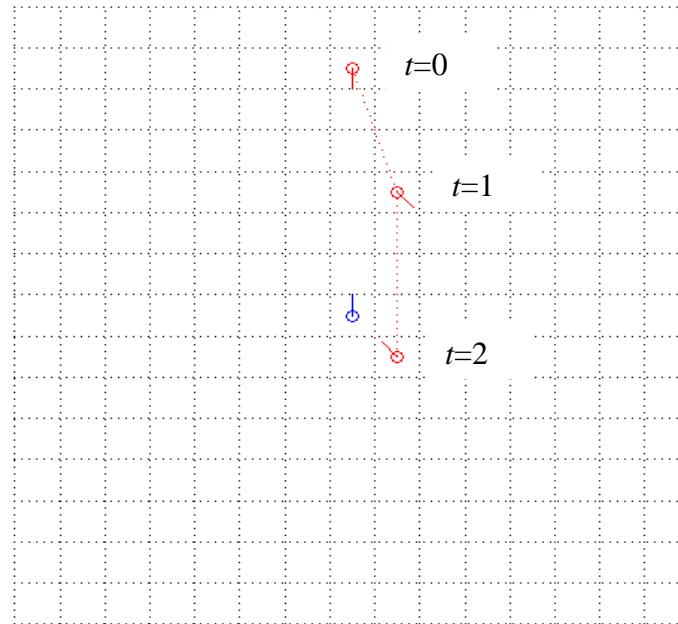
Time	Blue	Red
1	slow straight	fast left
2	fast left	slow right

Other Applications

- **Engagement Simulations**
  - Model threat aircraft avoidance maneuvers
  - Model contributions of Defensive Counter Air
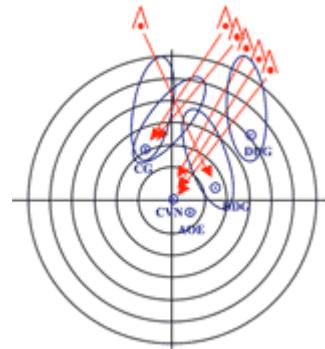
- **Pilot Training**
  - Provide realistic simulated adversaries

- **Other Tactical / Doctrinal Arenas**
  - Air and missile defense
  - Electronic warfare